Task 3.3 Laboratory Investigations

two dimensional testing : The Zeebrugge Breakwater

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COMMISSION
OF THE EUROPEAN
COMMUNITIES

MAST III

THE OPTIMISATION OF
CREST LEVEL DESIGN OF
SLOPING COASTAL STRUCTURES
THROUGH PROTOTYPE
MONITORING AND MODELLING

OPTICREST

MAS3-CT97-0116

REPORT

Task 3.3

Laboratory investigations : Two dimensional testing

The Zeebrugge breakwater

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Summary
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Content

1 Introduction

This summary describes two-dimensional model tests of the Zeebrugge breakwater performed by FCFH (Flemish Community Flanders Hydraulics) in the project MAS03-CT97-0116 "The optimisation of crest level design of sloping coastal structures through prototype monitoring and modelling" (OPTICREST) within the Mast III framework of EU.

The objectives of these two-dimensional model tests were to study wave run-up and overtopping and to model measured prototype storms.

2 Description of the model

The Zeebrugge breakwater (except the core) has been scaled 1:30 using the Froude criterion. In order to model the flow in the core properly, a scale of 1:20 for the core material [1] has been chosen.

The layout of the model [2] is shown in figure 2. An important adaptation in the cross-section is the slope of the breakwater. Design drawings mention 1/1.5 but measurements [4] proved that the slope in prototype is somewhat steeper. The model has been built with a slope of 1/1.3 in order to simulate wave run-up in prototype as close as possible.

The foreshore has been modelled up to 600 m in front of the breakwater to include the bar at approximately 550 m. The foreshore is shown in figure 1.

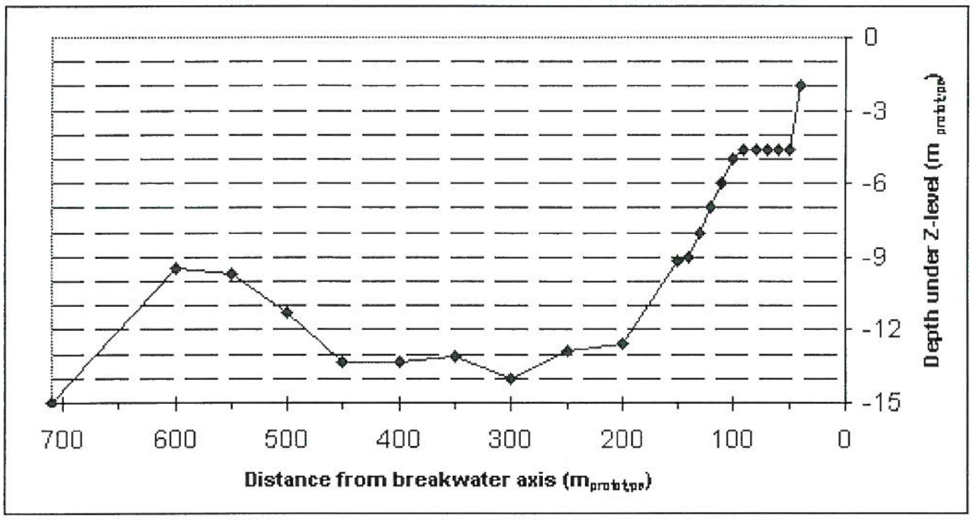

Figure 1 : The foreshore in front of the Zeebrugge breakwater.

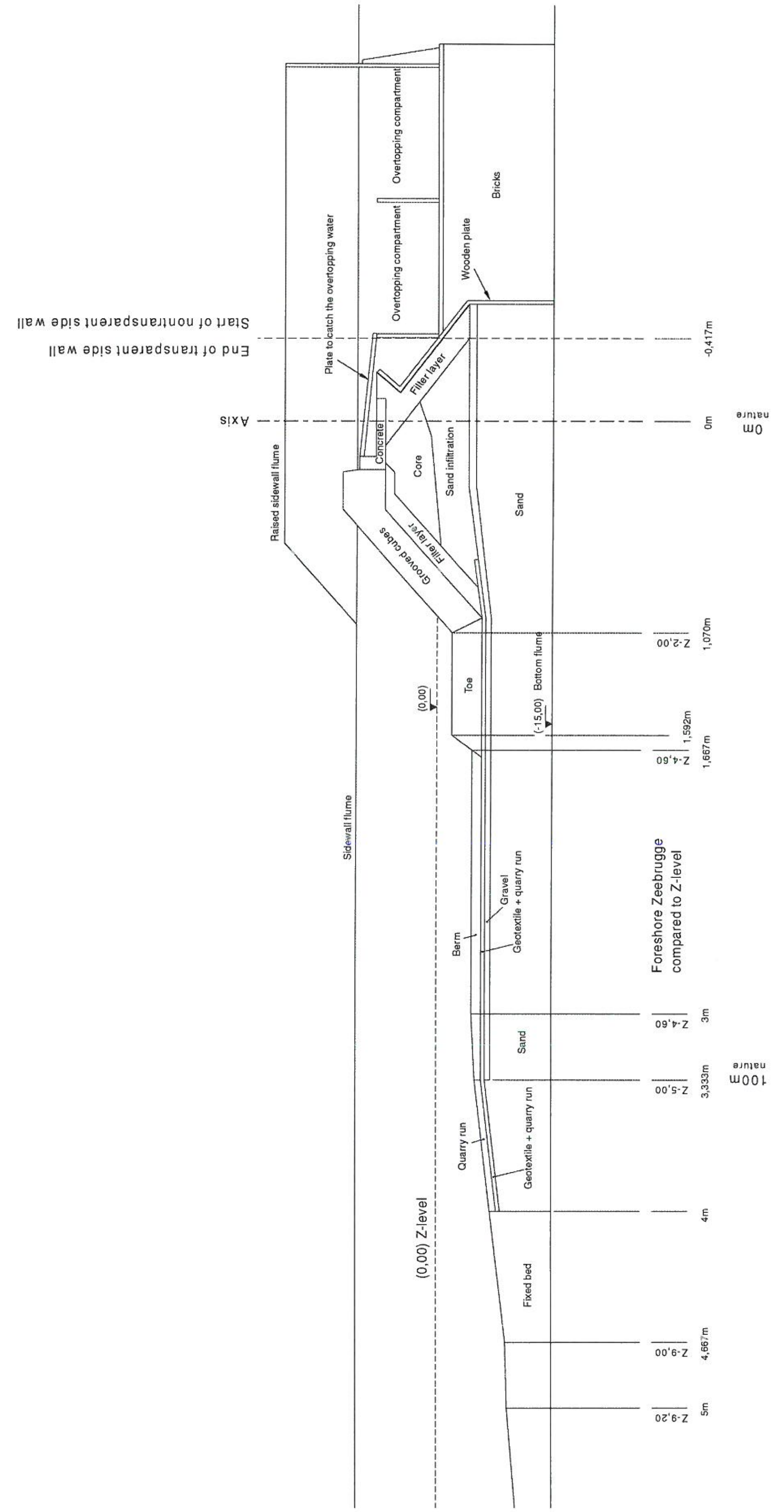

Figure 2 : Layout of the Zeebrugge model.

In the case of the Zeebrugge breakwater, the permeability of the breakwater plays a prominent part in the wave run-up. Therefore it was important to place the Antifer cubes in the top layer according to a record of the actual position in prototype. Also the sand levels measured in the breakwater core were modelled. During the tests, it was ascertained that this sand infiltration in the model was partly washed out.

Wave measurements were done at locations corresponding ~~with~~ to wave measurements in prototype.

Run-up measurements have been carried out with 2 different instruments [3].
3 sloping gauges parallel to the breakwater surface (see figure 3a) resulted in 2 run-up signals. The first one is the signal measured by the lowest run-up gauge, the second one is an extrapolation of all 3 run-up measurements towards the breakwater surface. These run-up signals were not reliable due to the different distances between the gauges and every single cube.
An improved accuracy has been obtained with a digital stepgauge (see figure 3b) that was able to follow the pattern of the cubes.

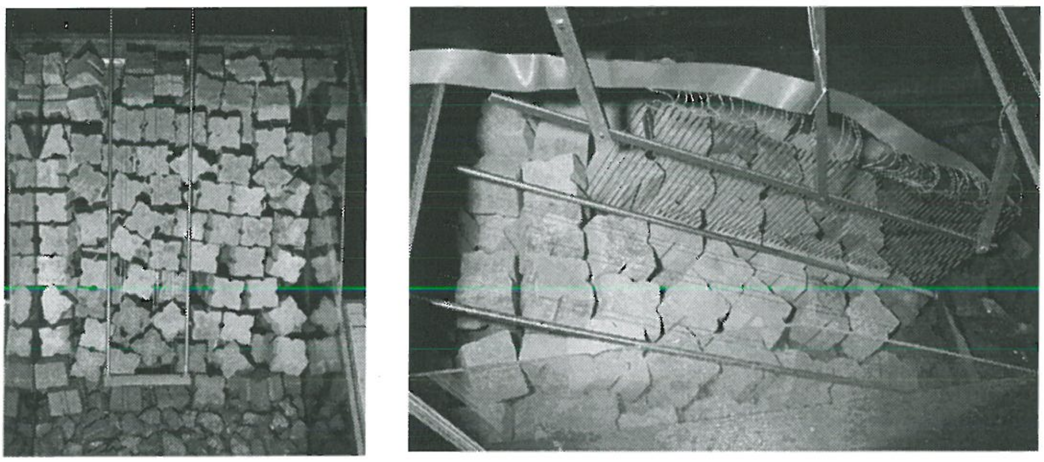

Figure 3 : Run-up gauges : (a) sloping gauges, (b) stepgauge.

The amount of overtopping water was measured as a total volume after each test. Only very few overtopping events occurred.

3 Results

15 storm periods were modelled to compare results of model tests with prototype measurements in Zeebrugge. It concerns 5 tests reproducing 5 different storm periods at high water level, and 10 tests reproducing 2 different storms divided into 5 storm periods each around high water.

To reproduce the storms an iterative procedure has been applied to obtain similar shapes of the wave energy spectra in model and in prototype offshore. The agreement of all reproduced spectra is considered acceptable for the present investigation.

For example figure 4 shows the comparison of the wave energy spectra in model and in prototype for 5 storms at high water level. The peak period is close to the target, the difference in T_{m01} is somewhat larger due to more energy at f_p and slightly less energy at higher frequencies. The average difference in T_{m01} is 8.5%, in H_{m0} 5.2%.

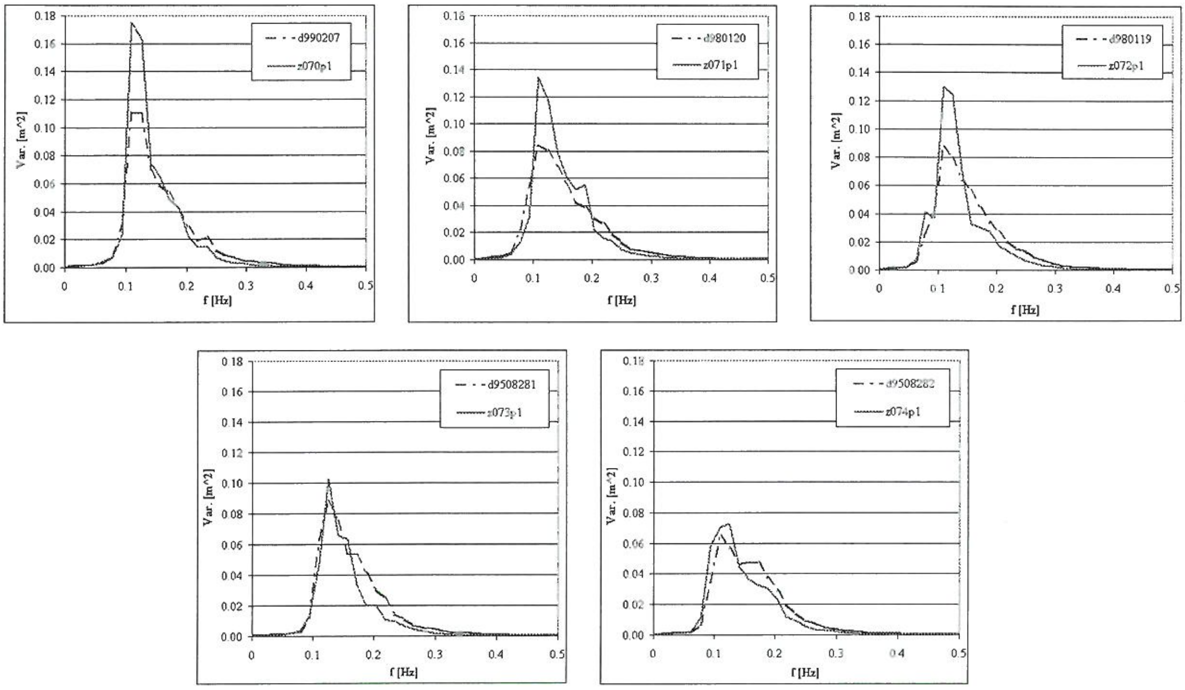

Figure 4 : Comparison wave energy spectra in model and in prototype (storms z070-z074).

Table 1 summarises the measurements of the 7 storm periods at high water.

Test	z070p1	z071p1	z072p1	z073p1	z074p1	z101c1	z102c1
Prototype							
H_{m0} [m]	3.13	3.01	2.95	2.87	2.68	3.01	2.58
$Ru_{2\%}$ [m]	5.42	5.37	5.09	4.27	4.43	5.55	4.76
$Ru_{2\%}$ / H_{m0} [-]	1.73	1.79	1.73	1.49	1.66	1.85	1.84
Model							
H_{m0} [m]	3.34	3.17	2.98	2.54	2.64	3.08	2.56
$Ru_{2\%}$ [m]	4.63	4.46	4.57	3.76	3.76	4.42	4.02
$Ru_{2\%}$ / H_{m0} [-]	1.39	1.40	1.53	1.48	1.42	1.44	1.57
Difference							
H_{m0} [%]	6.7%	5.4%	1.1%	-11.6%	- 1.4%	2.2%	-0.6%
$Ru_{2\%}$ [%]	-14.6%	-17.0%	-10.2%	-12.0%	-15.1%	-20.3%	-15.5%
$Ru_{2\%}$ / H_{m0} [%]	-19.9%	-21.5%	-11.4%	- 0.6%	-14.2%	-22.0%	-15.0%

Table 1 : Summary of the storm periods at high water.

The difference between model and prototype is between 0.6% and 11.6% for H_{m0}, between 10.2% and 20.3% for $Ru_{2\%}$ and between 0.6% and 22.0% for $Ru_{2\%}/H_{m0}$. In the model the average of $Ru_{2\%}/H_{m0}$ is approximately 1.46 whereas this value equals 1.73 in prototype. Important conclusion is the fact that run-up is smaller in model than in prototype for comparable wave conditions.

Table 2 and table 3 summarise the measurements of the 2 storms divided into 5 storm periods around high water.

	HW-3 - HW-2	HW-2 - HW-1	HW-1 - HW+1	HW+1 - HW+2	HW+2 - HW+3
Test	**z101a1**	**z101b1**	**z101c1**	**z101d1**	**z101e1**
Prototype					
H_{m0} [m]	2.34	2.74	3.01	2.89	2.48
$Ru_{2\%}$ [m]	5.92	6.01	5.55	5.49	5.77
$Ru_{2\%}$ / H_{m0} [-]	2.53	2.19	1.85	1.90	2.33
Model					
H_{m0} [m]	2.74	3.00	3.08	2.98	2.62
$Ru_{2\%}$ [m]	3.46	4.39	4.42	4.39	4.12
$Ru_{2\%}$ / H_{m0} [-]	1.26	1.46	1.44	1.47	1.57
Difference					
H_{m0} [%]	17.1%	9.5%	2.2%	3.1%	5.8%
$Ru_{2\%}$ [%]	-41.6%	-27.0%	-20.3%	-20.1%	-28.5%
$Ru_{2\%}$ / H_{m0} [%]	-50.1%	-33.3%	-22.0%	-22.5%	-32.4%

Table 2 : Summary of storm z101 around high water.

	HW-3 - HW-2	HW-2 - HW-1	HW-1 - HW+1	HW+1 - HW+2	HW+2 - HW+3
Test	**z102a1**	**z102b1**	**z102c1**	**z102d1**	**z102e1**
Prototype					
H_{m0} [m]	2.52	2.62	2.58	2.52	2.16
$Ru_{2\%}$ [m]	5.86	5.81	4.76	5.41	4.83
$Ru_{2\%}$ / H_{m0} [-]	2.33	2.22	1.84	2.15	2.24
Model					
H_{m0} [m]	2.80	3.01	2.56	2.80	2.49
$Ru_{2\%}$ [m]	3.84	4.51	4.02	4.11	3.34
$Ru_{2\%}$ / H_{m0} [-]	1.37	1.50	1.57	1.46	1.34
Difference					
H_{m0} [%]	11.3%	15.0%	-0.6%	11.3%	15.4%
$Ru_{2\%}$ [%]	-34.4%	-22.4%	-15.5%	-24.1%	-30.8%
$Ru_{2\%}$ / H_{m0} [%]	-41.1%	-32.5%	-15.0%	-31.8%	-40.1%

Table 3 : Summary of storm z102 around high water.

The differences between model and prototype become larger at lower water level. This can clearly be seen in figure 5. As opposed to prototype, no larger dimensionless run-up $Ru_{2\%}/H_{m0}$ was measured at lower water level in the model.
These differences can be caused by many factors such as differences in permeability, the pattern of the 2 Antifer layers, different sand infiltration levels, slightly different measurement systems, imperfect modelling of target spectra, effects of wind and current, model effects and scale effects (viscous effect).

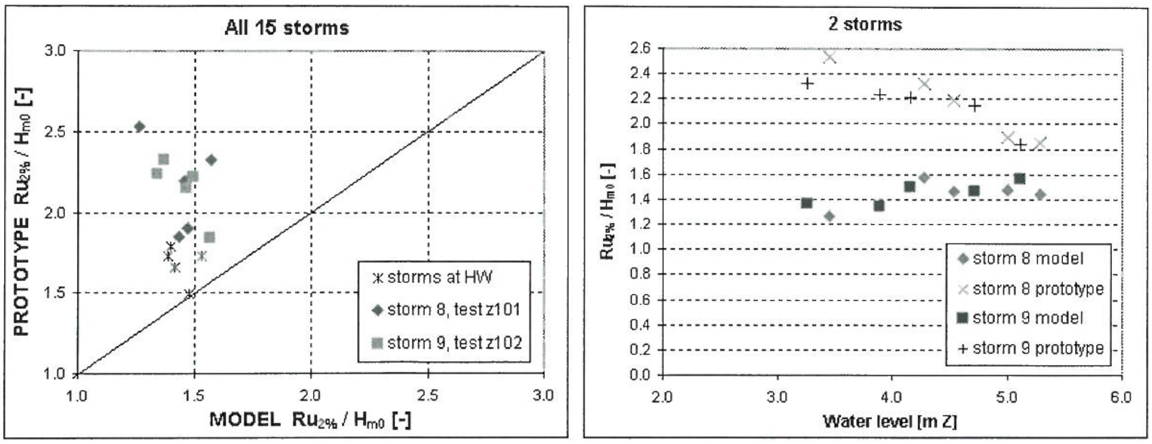

Figure 5 : Comparison of the dimensionless run-up for all storms.

The influence of the pattern of the cubes beneath the electrodes of the stepgauge has been examined. The upper 10 electrodes were located on top of a hole between the cubes. To examine its influence on run-up measurements this hole was partly filled to prevent water going down in stead of being registered by the stepgauge (see figure 6).

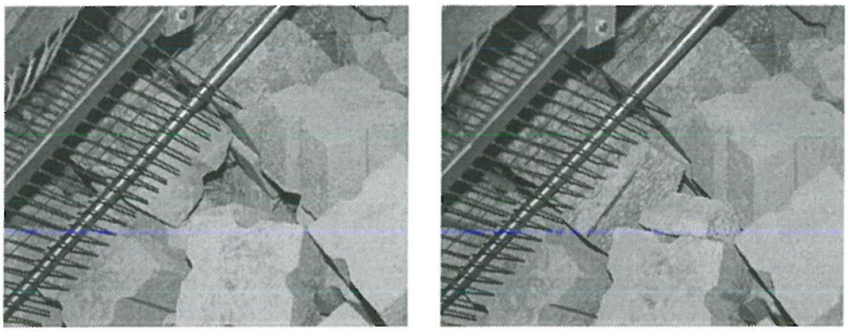

Figure 6 : Hole between cubes : (a) original pattern, (b) hole partly filled.

The results showed a clearly larger run-up measured by the stepgauge ; the dimensionless run-up $Ru_{2\%}/H_{m0}$ was approximately 25% larger in this specific set-up. It can be concluded that the pattern of the cubes has a large impact on run-up measurements. This is due to the fact that wave height, run-up level and its variation are of the same order of the dimensions of the Antifer cubes.

A limited range of all wave parameters was investigated by simulating the prototype storms. Within these ranges it is shown that the dimensionless run-up $Ru_{2\%}/H_{m0}$ gives a very consistent estimate of the run-up. In these two-dimensional model tests the overall $Ru_{2\%}/H_{m0}$ value equals approximately 1.45, whereas this values is approximately 1.7 in prototype.

4 Conclusions

The reproduction of 7 prototype storms at high water level showed that the dimensionless run-up $Ru_{2\%}/H_{m0}$ is underestimated 10%-20% when comparing with prototype measurements. The model results differed even more at lower water levels.

A number of factors can be responsible for the smaller run-up in the model :

- differences in permeability,
- the pattern of the 2 Antifer layers,
- different sand infiltration levels,
- slightly different measurement systems,
- imperfect modelling of target spectra,
- effects of wind and current,
- scale effects (viscous effect)
- model effects ...

The research within this project made it not possible to quantify the influence of these factors.

Extra tests are carried out to examine the influence of the pattern of the cubes beneath the electrodes of the stepgauge.
In one hole beneath the stepgauge an extra cube is placed. This modified pattern results in higher run-up values measured by the stepgauge. Thus it seems that the pattern of the cubes is critical for the measured run-up.

Extra tests carried out with a slightly different pattern of the cubes beneath the electrodes of the stepgauge, showed clearly a large impact of the pattern of the cubes on run-up measurements. It is supposed that this is due to the fact that wave height, run-up level and its variation are of the same order of the dimensions of the Antifer cubes.

5 Acknowledgements

The results obtained from this physical model were only made possible thanks to close co-operation of all partners of the Opticrest project.

6 References

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